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V. S. Golubev, et al

Foreign Technology Division
Wright-Patterson Air Force Base, Ohio

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by

V. S. Golubev, V. A. Gurashvili

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А а	*А а*	A, a	Р р	*Р р*	R, r
Б б	*Б б*	B, b	С с	*С с*	S, s
В в	*В в*	V, v	Т т	*Т т*	T, t
Г г	*Г г*	G, g	У у	*У у*	U, u
Д д	*Д д*	D, d	Ф ф	*Ф ф*	F, f
Е е	*Е е*	Ye, ye; E, e*	Х х	*Х х*	Kh, kh
Ж ж	*Ж ж*	Zh, zh	Ц ц	*Ц ц*	Ts, ts
З з	*З з*	Z, z	Ч ч	*Ч ч*	Ch, ch
И и	*И и*	I, i	Ш ш	*Ш ш*	Sh, sh
Й й	*Й й*	Y, y	Щ щ	*Щ щ*	Shch, shch
К к	*К к*	K, k	Ъ ъ	*Ъ ъ*	"
Л л	*Л л*	L, l	Ы ы	*Ы ы*	Y, y
М м	*М м*	M, m	Ь ь	*Ь ь*	'
Н н	*Н н*	N, n	Э э	*Э э*	E, e
О о	*О о*	O, o	Ю ю	*Ю ю*	Yu, yu
П п	*П п*	P, p	Я я	*Я я*	Ya, ya

*ye initially, after vowels, and after ъ, ь; e elsewhere. When written as ё in Russian, transliterate as yё or ё. The use of diacritical marks is preferred, but such marks may be omitted when expediency dictates.

GREEK ALPHABET

Alpha	Α	α	∝	Nu	Ν	ν	
Beta	Β	β		Xi	Ξ	ξ	
Gamma	Γ	γ		Omicron	Ο	ο	
Delta	Δ	δ		Pi	Π	π	
Epsilon	Ε	ε	ϵ	Rho	Ρ	ρ	ϱ
Zeta	Ζ	ζ		Sigma	Σ	σ	ς
Eta	Η	η		Tau	Τ	τ	
Theta	Θ	θ	ϑ	Upsilon	Υ	υ	
Iota	Ι	ι		Phi	Φ	φ	ϕ
Kappa	Κ	ϰ	κ ϰ	Chi	Χ	χ	
Lambda	Λ	λ		Psi	Ψ	ψ	
Mu	Μ	μ		Omega	Ω	ω	

RUSSIAN AND ENGLISH TRIGONOMETRIC FUNCTIONS

Russian	English
sin	sin
cos	cos
tg	tan
ctg	cot
sec	sec
cosec	csc
sh	sinh
ch	cosh
th	tanh
cth	coth
sch	sech
csch	csch
arc sin	$\sin^{-1}$
arc cos	$\cos^{-1}$
arc tg	$\tan^{-1}$
arc ctg	$\cot^{-1}$
arc sec	$\sec^{-1}$
arc cosec	$\csc^{-1}$
arc sh	$\sinh^{-1}$
arc ch	$\cosh^{-1}$
arc th	$\tanh^{-1}$
arc cth	$\coth^{-1}$
arc sch	sech^{-1}
arc csch	csch^{-1}

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rot	curl
lg	log

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SOME RESULTS OF THE INVESTIGATION OF MHD GENERATORS WITH NON-EQUILIBRIUM CONDUCTIVITY

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We surveyed the results of the investigations of MHD generators with non-equilibrium conductivity, and also of the physical properties of non-equilibrium plasma typical for such generators. The obtained results make it possible to conduct reliable valuable calculations of the MHD generators. We noticed questions which require further investigations.

The purpose of the cycle of investigations described below included the experimental realization of an MHD generator with non-equilibrium conductivity with a noticeable output of flow enthalpy in the form of electrical energy on the outer load. To achieve this goal it was necessary to investigate in detail the physical phenomena in the plasma of such an MHD generator and the factors which limit the effectiveness of the energy conversion, namely:

- the properties of the non-equilibrium plasma in an electric field,
- the effect of the transverse magnetic field on the stability and effective electrical conductivity of the plasma,
- the interaction of the gas flow with non-equilibrium plasma,

- the change in the hydrodynamic and thermodynamic parameters of the flow in the MHD channel during strong interaction.

We will point out a number of physical problems of the MHD generator with non-equilibrium plasma, which existed before the extensive investigations of this question [1].

1. The value of the factor of non-elastic losses of electron energy δ was unknown.

2. The region of applicability of the Saha equation to determine the electron concentration n_e required theoretical and experimental substantiation.

3. Solutions were required to the questions of the effective values of conductivity of inhomogeneous plasma in the transverse magnetic field and the Hall parameter, and also questions of the realized values of the load coefficient.

4. There were a number of questions on the behavior of the non-equilibrium plasma in the gas flow in the presence of a magnetic field; these are, in particular, phenomena at the input to the MHD channel and the hydrodynamics of flow stagnation.

5. Until now the basic question has been the maximum percentage of enthalpy which can be drawn from the flow on the outer load.

The physical investigations, which should have given the answer to the questions enumerated above and led to the creation of an efficient MHD generator, were expanded at the beginning of the sixties simultaneously in many laboratories throughout the world. The sequence of studying the posed questions was similar to their natural logical order:

1. The properties of low-temperature non-equilibrium plasma in an electrical discharge without a magnetic field: the balance of energy of he electron and the other components of the plasma, the conditions of ionization equilibrium, the current contraction of the plasma, etc.

2. The non-equilibrium low-temperature plasma in intersecting electric and magnetic fields, the instability of such a plasma (ionization, acoustical, and others), the effective conductivity and Hall parameter, the boundary effect on the instability of the plasma and the geometry of the current course.

3. The non-equilibrium plasma in a gas flow: the ionization front and the ionization wave, the stability of the plasma on the front and the problem of the keep-alive electrode, the hydrodynamics of the inhomogeneous plasma in the flow in the presence of a magnetic field.

4. The realization of a self-sustaining electrical discharge due to the movement of the gas across the magnetic field.

5. The realization of energy output on the outer load of the MHD generator with a non-equilibrium plasma.

6. Realization of an MHD generator with effective conversion of the thermal energy of the flow into electrical energy.

In the future we will adhere to this sequence in the account of the development of the investigations.

Properties of the Non-equilibrium Plasma of a Gas Discharge.

We investigated the plasma without a magnetic field under conditions corresponding to the parameters of the plasma of the MHD generators:

concentration of neutral particles	$n_a \sim 10^{18}-10^{19} cm^{-3}$
concentration of cesium atoms	$n_s \sim 10^{14}-10^{16} cm^{-3}$
concentration of electrons	$n_e \sim 10^{13}-10^{15} cm^{-3}$
gas temperature	$T_a \sim 1000-2000°K$
electron temperature	$T_e \sim 2000-5000°K$
current density	$j \sim 1-10\ A/cm^2$
electric field strength	$E \sim 1-10\ V/cm$

Theoretical and experimental works [1-3], devoted to these investigations, lead to the following conclusions:

- In the case of a plasma of alkaline metals there is ionization equilibrium (i.e., the Saha formula was applicable) in the electron gas-excited atom ensemble, if the value $n_e > n_{kp} \sim 10^{13}-10^{14}$ cm^{-3}.

- The basic losses in emission correspond to the resonance transitions. The loss percentage in the resonance emission compared with the elastic losses is not great if $n_e > 10^{14} cm^{-3}$, $n_a > 10^{18} cm^{-3}$, while the minimum dimensions of the plasma $L \sim 1$ cm; i.e., $\delta \sim 1$.

On the basis of these conclusions it is possible to calculate all the parameters of the thermally non-equilibrium plasma with a magnetic field, using the equations of the balance of the electron energy, the gas energy and the Saha equation.

The Effect of a Transverse Magnetic Field on the Properties of a Non-equilibrium Plasma with a Current.

The newest and most significant results for plasma physics were obtained during the investigation of the behavior of a non-equilibrium plasma with a current in a magnetic field. The basic results of these investigations lead to the acceptance of the fact that under conditions of an MHD generator with a non-equilibrium plasma, the conductivity has an ionizing-turbulent nature.

1. Abnormal resistance and the Hall parameter of an inhomogeneous plasma. It was theoretically shown in [4-7] that in the presence of inhomogeneities of conductivity σ, and relative amplitude $\Delta = \langle (\delta\sigma/\sigma)^2 \rangle^{1/2}$ it is possible to write the following expression for effective conductivities and the Hall parameter

$$\frac{\sigma_{эфф}}{\langle\sigma\rangle} = \frac{\beta_{эфф}}{\langle\beta\rangle} = \left[1 + f \langle\beta\rangle^2 \Delta^2\right]^{-m} \qquad (1)$$

where $f = Cos^2 \vartheta$, $m = 1$ one-dimensional inhomogeneities in the form of flat layers, parallel to the lines of force of the

magnetic field, and whose normal is inclined at angle θ to the average current,
$f=1$, $m=1/2$ - two-dimensional inhomogeneities with isotropic and isometric distribution of the "ups" and "downs" of the conductivity, $f=\frac{3\pi}{8}$, $m=2/3$ - three-dimensional isotropic inhomogeneities.

The knowledge of the value $\Delta(\beta)$ is possible only with the discovery of the physical nature of the plasma inhomogeneities. As the nonlinear analysis of ionization instability and the numerous experimental works show, when $\beta \gg 1$ universal relationships occur:

$$\beta_{э\varphi\varphi} \simeq const \sim 1 \qquad (2)$$

$$\sigma_{э\varphi\varphi} = \frac{e\langle n_e\rangle \beta_{э\varphi\varphi}}{B} \qquad (3)$$

The results of various works [8-9] when $\frac{T_e}{T_a} - 1 > 0,1$ as well as when $T_e/T_0 \gg 1$ confirm (2-3); this is reflected in Fig. 1. These relationships are also valid for practically visually homogeneous plasma ($\Delta \lesssim 0.1$), which is probably connected with the presence of small-scale inhomogeneities which require special experiments with a high three-dimensional solution on very small scales ($L \ll 10^{-1}$ cm) to observe them. As for relationships (1) they have not as yet received convincing quantitative confirmation in the experiments.

2. Ionization Instability and Ionization Turbulence. Since this excellent survey [11] is devoted to this fundamental phenomenon which is first pointed out in [10], we will not go into detail about this problem but will only point out the new interesting experimental data.

It is well known that even during complete ionization of the additive, when the ionization instability actually does not develop, the value of the effective Hall parameter $\beta_{э\phi\phi}$ remains small. Special measurements [12] of the value $\beta_{э\phi\phi}$, in plasma with complete additive ionization within a wide range

$n_e = n_s = 5 \cdot 10^{11} - 10^{14} cm^{-3}$, showed (Fig. 2) that $\beta_{э\phi\phi}$ increases with a decrease in n_e. This fact makes it possible to assume that the "saturation" of $\beta_{э\phi\phi}$ was possibly caused by some microturbulence of a kinetic nature, damped by collisions of ions with neutrals when the mean free path becomes less than the Debye radius (i.e., with small n_e).

3. Acoustical Instability. The physical reason for this instability includes the build-up of sonic vibrations by fluctuations of the ponderomotive force $\vec{J} \times \vec{B}$ [13]. The effect of Joule heat release on this process was studied in [14]. The experimental observation of the acoustical waves in the form of layers perpendicular to the average current and moving at a rate on the order of sound ($\sim 2 \cdot 10^5$ cm/s) was reflected in [15]. The interesting experimental results with respect to the build-up of sonic vibrations by the fluctuations of Joule heat release were given in [16], where, in the discharge of coaxial geometry, we succeeded in finding the threshold of sonic vibrations with respect to β and j^2/σ.

The Interaction of a Non-equilibrium Plasma with a Gas Flow

The phenomena which occur at the input to the MHD channel are of interest from the point of view of the problem of the keep-alive electrode. Basically, these phenomena are connected with the input relaxation of non-equilibrium conductivity, converted under certain conditions to the ionization wave. An evaluation of the length of the input relaxation can be made from the equation of electron energy balance at the input to the MHD channel. Thus, for example, for the case of turbulent conductivity

$$L_{вx} \simeq \frac{I}{uB} \ln\left(\frac{n_e}{n_{e\,вx}}\right) \tag{4}$$

where $n_{e\,ax}$ - concentration of electrons at the input,
I - ionization potential.

Under real conditions $L_{вх} \sim 3 \div 10$ cm. Since the length of the input relaxation depends on many factors (poor emission of electrodes, scale of experiments, etc.), the keep-alive electrode set-up is expedient even in the case of weak "detachment" T_e/T_a [17]. The phenomenon of the ionization wave was studied theoretically [18] for the case of the transfer of energy by electron thermal conductivity. The speed of the ionization wave front in this case is given by the expression:

$$\vartheta_\varphi = \left(\frac{I}{T_e}\right)^{3/2} \sqrt{\frac{T_e}{m_a}} \qquad (5)$$

where m_a - mass of the neutral. The absolute values ϑ_φ, measured in the experiments [19] without a gas flow were $\sim 5 \cdot 10^2 - 5 \cdot 10^3$ cm/s. The experiments with a gas flow [20] gave the values $\vartheta_\varphi \sim 10^4 - 5 \cdot 10^4$ cm/s, which can be explained only by the gas dynamic turbulent transfer of electron energy. The corresponding mechanism of rate transfer of the ionization wave [21] is given by the expression:

$$\vartheta_\varphi^T \simeq 2 \sqrt{D_T \frac{T_e}{I} \frac{3 m_e}{m_a} \nu_e} \qquad (6)$$

where D_T - coefficient of turbulent diffusion, for real conditions $D_T \sim 10^4$ cm^2/s,
ν_e - frequency of the electron collisions,
m_e - mass of the electron.

Expression (6) gives the correct order of the value ϑ_φ^T. Thanks mainly to the hydrodynamic turbulence of the flow the work of the keep-alive electrode is facilitated.

The Realization of the MHD Generator with Non-equilibrium Conductivity

It is possible to point out the basic operations with respect

to the realization of the MHD generator. Work [22], in experiments with disk channels, used a keep-alive electrode, having created a plasma screen at the input to the channel (Fig. 3), which continuously passed into the plasma of the generator. It was also shown [20] that the discharge in the channel exists because of the force $\vec{u} \times \vec{B}$, and not because of the scattered electrons, as a result of which the plasma ring created by the keep-alive electrode existed in the channel significantly longer than the operation time of the keep-alive electrode.

On the same set-up as was used in [20], we carried out experiments with a linear channel [23], in which the specific electric capacity released in the outer load reached $\sim$100 W/cm^3.

It is necessary to note the operations carried out in the shock tubes [24, 25] with disk and linear channels, in which the effectiveness of the energy conversion reached $\sim$10%.

A large cycle of investigations was also satisfied in [17].

In the experiments in [26] a certain cycle of investigations was completed, in which the supersonic flow of an argon-cesium plasma was effectively stagnated. The experiments were conducted on a sectioned Faraday MHD generator (Fig. 4) with a shock tube (Fig. 5) as a source of the plasma. The MHD channel with Mach 2.5 did not have a keep-alive electrode; therefore, the experiments were conducted with stagnation temperature T=5000-9000°K. The stagnation pressure reached 20 atm (abs.), the magnetic field to 4 T, the concentration of cesium in the MHD channel to 10^{15} cm^{-3}. In these experiments significant conversion factors were attained, when T=7500°K - 20%, and when T=9000°K - 30%. During the experiments we measured all the determinant parameters of the plasma and the MHD generator, including the distribution of the Mach number along the channel under load conditions. Having confirmed the basic representations on the nature of the conductivity ("turbulent" law $\sigma \sim \beta^{-1}$), the presence of the developed ionization

instability (Fig. 6) etc., these investigations detected two experimental facts, whose explanation requires additional investigations.

First of all, there are abnormally large values of the factor of non-elastic losses of electron energy δ, which reached $\sim$50 in the experiments. A similar effect was observed in [27]. A possible explanation of the abnormally large value of δ is the presence of a hypothetical microturbulent plasma.

If ions participate in this microturbulence, they quickly return the neutral gas to the energy of its own vibrational movement, derived from the energy of the current electrical field in the process of maintaining microturbulence. This leads to an increase in the apparent factor of non-elastic losses of electron energy and their collisions with gas.

Consideration is given to the lack of a flow "stall" with a significant output of energy (20-30%) in the outer load under conditions of a relatively weak (70%) increase in the cross section of the channel. The experimental determination of the Mach number showed that the flow remains essentially supersonic, i.e., the gas must be slightly heated or even cooled, in spite of the significant volumetric heat releases. A possible explanation for this paradox is the generation of strong acoustical vibrations with the input of the supersonic flow into the channel, where the flow passes to the three dimensional-inhomogeneous zone of the stagnation forces $j_y \cdot B$ and $j_x \cdot B$. It is possible to show that for waves running from the cathode wall to the anode wall, the mechanism of amplification - force, i.e., because of the fluctuations of the ponderomotive force $j \times B$, while for waves running along the channel, the mechanism of amplification - heat, i.e., because of the fluctuations of heat release j^2/σ. For the time of the passage of the gas through the channel, the amplitude of the acoustical waves in the direction across the flow of the channel from the evaluations can slightly increase, at the same

time as the amplitude of the waves along the channel can appear significant ($\Delta P/P \sim 1$). If we assume that the significant part of the Joule heat capacity is spent on the build-up of sonic vibrations and is not transmitted to the heating of the gas, then the experimental distribution of the Mach number along the channel can be explained.

CONCLUSIONS

Thus, as a result, investigations lasting more than ten years on plasma physics and the magnetic hydrodynamics of MHD generators with non-equilibrium conductivity can confirm that presently:

- Calculations of the properties of a non-equilibrium plasma in an electric field are reliable.
- Briefly, the basic physical processes in a non-equilibrium plasma with a magnetic field and an effective conductivity nature are clear; a description is given of the work of the keep-alive electrode and the various physical mechanisms affecting the processes which occur at the input to the channel.

Nevertheless there are still a number of basic questions which require further investigations.

- the physical mechanism of the "saturation" of the Hall parameter in a macroscopic homogeneous plasma,
- the reason for the abnormally large factor of non-elastic losses of electron energy,
- the properties of the developed acoustical instability and the conditions for its appearance in an MHD generator with strong stagnation.

The entire investigation makes it possible, nevertheless, to conduct reliable evaluations of the MHD generators with non-equilibrium conductivity, if the interest in these programs is maintained.

BIBLIOGRAPHY

1. J.L.Kerrebrock, M.A.Hoffman, AIAA Journ. 1964, 2,N 6, 1080-1087.
2. M.L.Lutz, AIAA Journ.1967, 5,N 8, 1416-1423.
3. Л.М.Бибермэн и др. "МГД метод получения электроэнергии". Изд. "Энергия", Москва, 1968, 209-263.
4. R.J.Rose, Phys.Fluids, 1962, 5,N 9, 1081.
5. Е.П.Велихов, А.М.Дыхне, И.Я.Шипук. Труды УП Межд.Симп. по иониз.явлениям в газах. Белград, 1965.
6. А.М.Дыхне. ЖЭТФ, 59,№ 2(8), 641.
7. Ю.А.Дрейзин, А.М.Дыхне. Труды конф.по теории плазмы, Киев, 1972, 166-172.
8. Electricity from MHD, Ed. IAEA, Vienna, 1966.
9. Proc.of 5th Intern.Conf.on MHD Electr.Pow.Gener. Munich, 1971.
10. E.P.Velikhov, A.M.Dykhne, 6th Conf.on Ioniz.Phen.in Gases, Paris,1963, vol.4,p.511.
11. V.Zampaglione, "Ionization Instability..." CNEN-RT/FI (73)42.
12. Е.В.Даньщиков, В.С.Голубев, Ф.В.Лебедев. Доклад на X заседании Межд.Группы Связи по МГДГ, Вена, 1974.
13. Е.П.Велихов. Доклад на I Межд.конф.по МГДГ. Ньюкасл, 1961.
14. I.E.McCune. Proc.of 2d Intern.Symp.on MHD, Paris, 1964.
15. С.В.Пашкин, И.Я.Шипук. ДАН СССР, 1967, 196,№6,1275-1281.
16. В.С.Голубев, Ф.В.Лебедев. ТФВТ, 1974, 12 № 2.
17. E.Bertolini et all. Proc.of 13th, Symp.on Eng. Aspects of MHD. Stanford USA,1973,1-1.

BIBLIOGRAPHY (cont.)

18. Е.П.Велихов, А.М.Дыхне. Труды 7-го Медд.Симп.по иониз. явл. в газах. Белград, 1965.
19. В.Т.Карпухин, А.В.Недоспасов. ТФВТ, 1970, 8, №2, 266.
20. А.Ф.Витшас, В.С.Голубев, см. 3 , стр.292-303.
21. В.С.Голубев, М.М.Маликов. ТФВТ, 1973, II, №4.
22. А.Ф.Витшас, В.С.Голубев, "Атомная энергия", 1967, 23, № 4, 291-295.
23. В.С.Голубев, М.М.Маликов, А.В.Недоспасов. ТФВТ, 1970, 8,№6, 1265-1272.
24. B.Zanderer, E.Vate. See [17] .
25. J.F.Louis. Proc.of 8th Symp.on Eng.Asp.of MHD, Stanford, 1967.
26. А.Д.Белых, В.А.Гурашвили, В.С.Голубев. ТФВТ, 1973, II, №6.
27. S.Shiode, I.Yamashita, H.Yamamoto. See [17], 1-3.

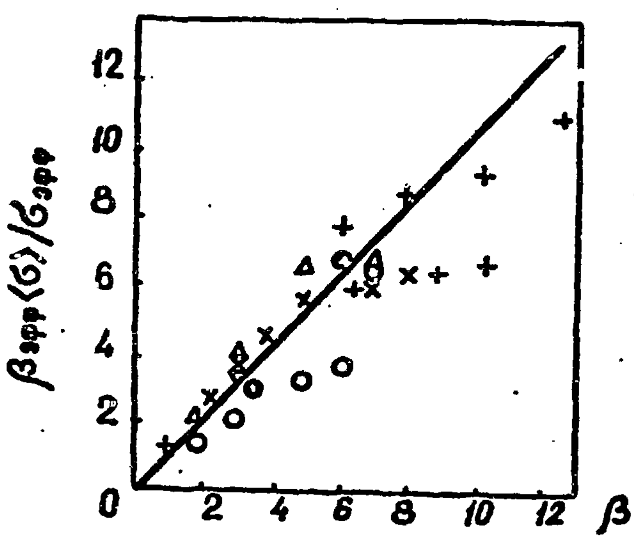

Fig. 1. Value $\frac{\langle\sigma\rangle}{\sigma_{эфф}}\cdot\beta_{эфф}=f(\beta)$ from the data of different experiments.

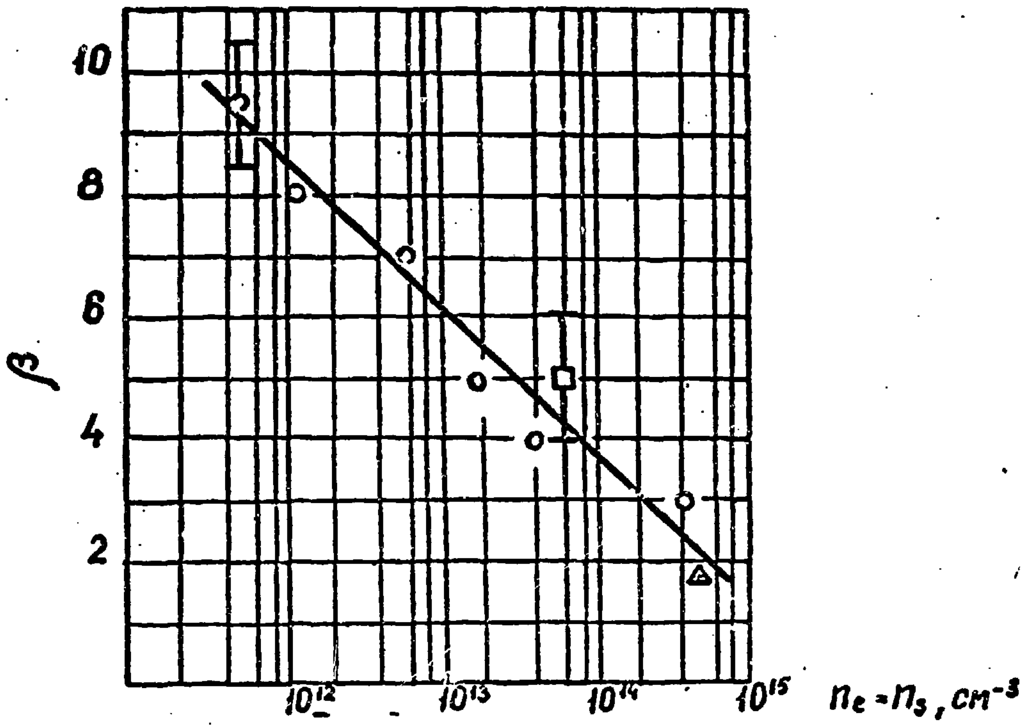

Fig. 2. Measured values of $\beta_{эфф}$ in different experiments, when β=10 and n_e=n_s.

—o— (Ar-Cs, T_a= 400°K, n_a= 10^{18} cm^{-3})
—□— (Ar-Cs, T_a=1500°K, n_a = 5·10^{18} cm^{-3})
-·-o— (Ar-Hg, T_a = 400°K, n_a = 3·10^{18} cm^{-3})
-·-Δ— (Ar-Cs, T_a = 500°K, n_a = 3·10^{18} cm^{-3})

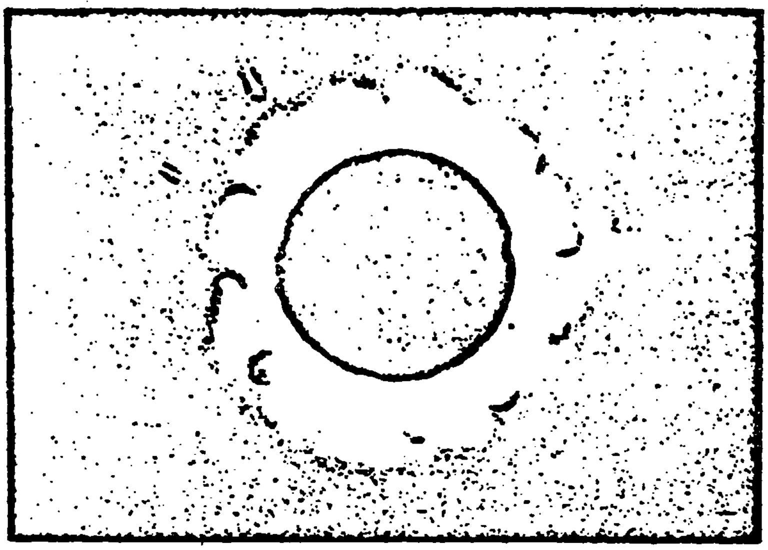

Fig. 3. Outer view of the plasma in an arc keep-alive electrode of a disk channel.

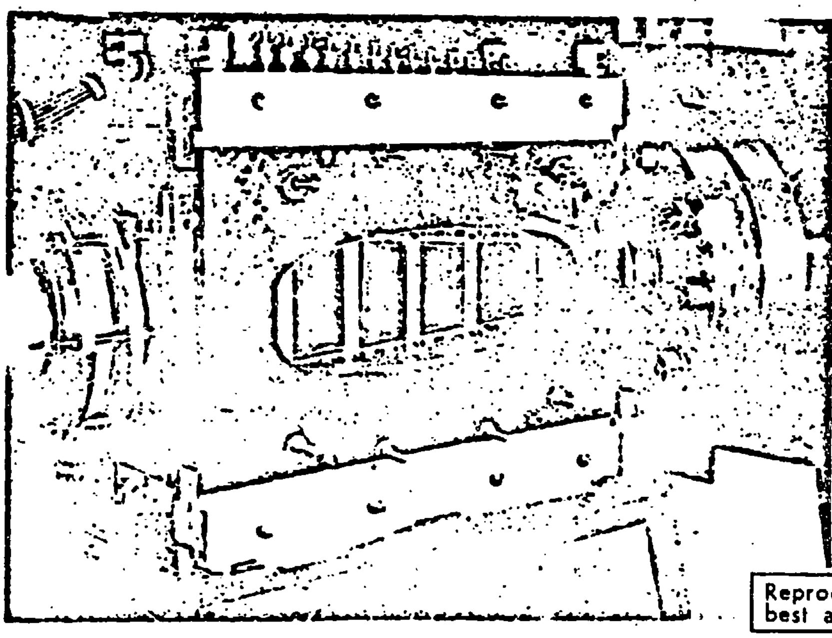

Fig. 4. MHD channel with a magnet.

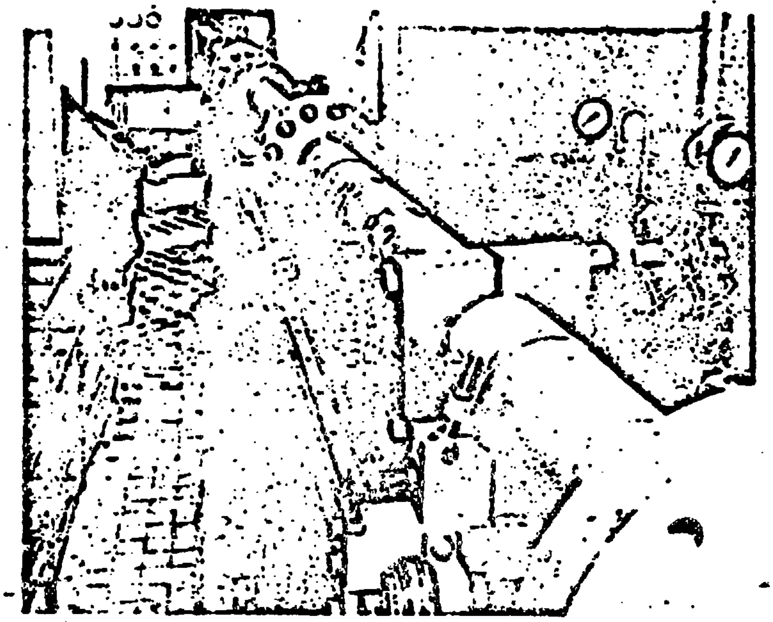

Fig. 5. General view of the shock tube.

Кадр 4

Кадр 3

Кадр 2

Кадр I

Fig. 6. Outer view of the plasma in a channel of the MHD generator at T=7500°K, V=4 T. The time interval between the frames - 100 μs. Exposure - 2 μs. Кадр=frame.